Chapter 14

The Role of Soil Properties in Plant Endemism – A Revision of Conservation Strategies

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Additional information is available at the end of the chapter

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1. Introduction

The soil as the support of all terrestrial ecosystems is distributed as a continuous landscape and varies according to drainage, geomorphology and litho-climatic conditions [1]. There are five major factors that control the formation of soil: parent materials, climate, biota, topography and time [2]. These factors present interdependence; for example contrasting climatic regimes are likely to be associated with contrasting types of vegetation. Nonetheless in certain situation one of the factors had the dominant influence in determining differences among of set of soil [3]. In addition processes of soil genesis are operating under the influence of environmental factors; therefore we can understand the relationship between particular soils and the landscape and ecosystem in which they function [4]. Climate is perhaps the most influential of the four factor acting on large geographical areas (large scale), contributing to the development of specific types of soils and vegetation patterns [5], such as Gelisols (tundra vegetation: lichens, grasses and low shrub), Histosols (water loving plants: pond weeds, cattails, sedges, reed, mosses), Spodosols (mainly coniferous species), Alfisols (deciduous forest), Mollisols (grasses), Aridisols (xerophytic plants), and Oxisols (tropical rain forest). However, at regional level (medium scale) soil variability is often related to small changes in topography and thickness of parent materials or to the effect of organism. In Trans-Mexican Volcanic Belt, is common finding soil sequences or catenas related with specific vegetation species such as Andosols (Pines-volcanic ashes), Cambisols (deciduous trees-colluvial material), fluvisols (crop lands-alluvial material) y solonchack (halophyte grasses-lacutrine material) [6]. Finally at local scales, variation in edaphic characters often provides the best statistical explanation for variation in floristic composition. Frequently, systematic variations in the parent material are closely related to endemism [7]. Endemic species have relatively narrow tolerance to changes in their environment, and can be dependant on certain geologic and edaphic features. There are studies that provide detailed information on species and plant communities, some include relief features, and others report physical and chemical analyses which allow us to infer about soil fertility [8,9] while some other studies have performed statistical analysis to correlate such variables [10-12]. This chapter presents a revision of the current knowledge on the role of soil properties as for pH, H_2O_2 reaction, and reactions to HCl in the distribution of endemic plant species and synthetize in table 1 studies that give details examples of this relationship (plant-soil endemicity).

Species/References	Soi/Substrate type	Technique	Results/Conclusions	Localities
Calochotusobispoensis, *C. tiburonensis*, *C. pulchellus* (Liliaceae) [40]	Serpentine	Concentrations of Ni and Cu in plant tissue	Three species are endemics	Coastal of California USA
Ariocarpus kotschoubeyanus (Cactaceae) [64]	Silty, dry lake beds	Cartographic method by conglomerates	This plant is an edaphic specialist	Chihuahuan Desert, Mexico
Satureja arkansana (Lamiaceae) and *Coreopsis lanceolata* (Asteraceae) [25]	Sandstone glade with alkaline soil	Soil pH	*Satureja arkansana* was absent on soil with a pH less than 6.1 In areas with soil pH greater than 6.1 *C. lanceolata* was absent	Arkansas USA
Hemizonia pungens ssp. *pungens* (Asteraceae) [20]	Alkali pools	Reciprocal transplant greenhouse experiment	This plant grows better on non-alkali soil when grown without competition	Yolo, California, USA
Guaiacum unijugum (Zygophyllaceae) [67]	Coastal dune and arroyo environments	Genetic analysis using microsatellite	The current extraction of gravel its habitat which could pose a direct threat	Baja California Sur, Mexico
Agave bracteosa, *A. victoria-reginae*, *A. albopilosa* *Brahea berlandieri* *Dasylirion berlandieri* *Hesperaloe funifera* var. *funifera* *Yucca filifera*	Litosols stoniness soils, summit, slopes, Stoniness soils depth soils	Sampling of 39 plots (1 Ha each one) all species were recorded and particle size, pH, depth and organic matter	It was observed that soil characteristics drastically alter the conformation of the vegetation and therefore species are not present	Northern Gulf Coastal Plain in northeastern Mexico

Species/References	Soi/Substrate type	Technique	Results/Conclusions	Localities
(All monocotyledons) [71]				
Lupinus subcarnosus (Leguminosae) [72]	Sandy soil	Allozymic variation in enzymes and other proteins	Edaphically restricted species is less genetically variable	East-central Texas USA
Lasthenia californica (Asteraceae) [73,74]	Serpentine soils	Genetic, physiological and phylogenetic studies	Races A and C of *L. californica* coexist on serpentine soil, but inhabit soil of differing physical and chemical properties	Palo Alto, California in the Santa Cruz Mountains USA
Coccoloba cereifera (Polygonaceae), [75]	Sandy soils, gravelly soils and quartzitic outcrops	Each 25 m^2 quadrant was classified according to soil types and were sampled for chemical and granulometric analyses	The spatial distribution of *Coccoloba* was largely related to the arrangement of sandfields	Serra Do Cipó, southeastern Brazil
Erigonum nervulosum (Polygonaceae) *Streptanthus brachatus* and *S. morrisonii* (Brassicaceae) [76]	Serpentine barren soils	Low concentrations of Ca, Mg, P, N	Differences in Ca and Mg between serpentine soils allow distinct species distribution	Lake County, California, USA

Table 1. Studies in which species distribution and soil features are reported.

2. Endemism

Endemic, in botany, means that a plant species is considered native to the country –region- where it can be found [13] and the term is applied to the distribution of organisms [14]. Although climatic factors are the most studied [15,16]; endemism is a non-ecological [17], geological event. Climate limits the flora [18,19], while geological characteristics largely define habitat diversity [4]. Moreover, edaphically severe habitats commonly support edaphic endemics, which are plant species that do not occur elsewhere [20]. Although that might be not enough to recognize the endemic species, edaphological characters (macro and micro) are essential to establish phylogenetic hypothesis of endemic taxa and areas of endemism, looking for consistency with geological models [21-23].

3. Soil

Soil, in soil taxonomy [24] is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface. Soil occupies space, and is characterized By one of the following: horizons or layers, that are distinguishable from the initial materials a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment.

We intend to clarify that for some plant species, soil has played an essential role in their evolution and current distribution. Therefore, it is necessary to indicate that according to soil taxonomy is not possible to classify the earthy materials used in pots in greenhouses. In the same sense, plants even grow on trees, but trees are regarded as non soil. Soil covers the earth's surface as a continuum, except on bare rock. Some endemics are restricted to a particular geological formation or to one type of rock or rock outcrops. Endemicity found on rocky outcrops, either calcareous or otherwise, has been reported by several researchers [25-31].

In order to understand the relevance of soil for plant endemism, it is necessary to highlight that the geological processes as genesis of unique soil types may provide the necessary isolation for the genesis of unique biota, and the edaphic factors are used to draw the link between environments and taxa [32]. If the environmental scenario is potentially multi-dimensional [33], some soil properties should be also considered as predictors. Previous research [2] considers that the distinction between soil and environment is arbitrary; and might constitute a theoretical artifact which does not represent natural processes.

3.1. Soil genesis

The transformation of rock into soil is designated as soil formation. Climate, organisms, relief, rocks, and the time are soil forming factors. Therefore, soil can be considered as a particular combination of its forming factors. For a given combination of factors there is only one soil type [2]. Soil properties such as pH, clay content, porosity, etc, are determined by the combination of these factors. The smallest change in any one of the properties, gives rise to a new soil.

Climate is usually considered the dominant soil forming factor, and cannot be described by a single index [4]; for example, the high proportion of smectite in soil, indicate a highly seasonal semiarid subtropical climate [34].

Living organism as bacterial species are able to fix N2, dissolved P, weathered extrusive igneous rock, marble, and limestone, and significantly mobilized useful minerals, such as P, K, Mg, Mn, Fe, Cu, and Zn in rock minerals [35]. Additionally, plant root systems alter the structure of the surrounding soil [36], and the roots of some plants have the ability to exude low-molecular-weight organic acids that produce changes in the availability of nutrients [37].

Relief modifies the water relationships in soils, affected by slope processes such as erosion, landslides and other mass movement [38-39]. However, little is known about the dynamics of soil mosaics formed by slope processes; whereby mountainous regions are characterized by high soil diversity.

The soil formation is regulated by the origin of parent material and by the age of the exposed surface. The nature of the parent material profoundly influences soil characteristics such as the chemical weathering and the quantity and type of clay minerals. While the total composition of the parent rocks is only one of the factors involved in soil formation, it is of considerable interest to analyze some of these rocks, and of soils of similar origin. The time of soils formation refers to the age of the exposed surface. The soils change with time and undergo a process of evolution [2].

3.2. Soil properties

Physical, chemical and mineralogical analyses are used in soil taxonomic criteria. For standard laboratory methods descriptions see Appendix of Keys to Taxonomy of Soils [24]. The diversity of soil properties resulted in the diversity of soil use and soil ecological functions [38,39]. In edaphic islands such as serpentine and limestone outcrops upon which plant grow are necessary specific analyses; per example, in ultramafic soil trace elements as Mn, Cu, Zn, Cr and the heavy metals Ni and Co are extracted, as well as in calcareous soils are measured soluble and exchangeable P [40,41]. Overall, previous authors agree that vegetation differences are strongly associated with differences in the bedrock [29,42].

4. Sampling approach

The existing literature comprises a wide range of sampling techniques to obtain vegetation samples. The plant populations may vary in size and in number of individuals per species. According to our field observations, it is necessary to select populations that adequately represent the endemic area (Figure 1). Soil sampling must be performed in the same locations where vegetation has been previously sampled. The overlap of both sampling activities allows correlating changes in vegetation and soil [43]. Thus, the resulting plots are clearly representative of the surrounding area. Accordingly, geology and topography are essential characteristics that need to be thoroughly examined. For instance, spatial variability studies have indicated that even when the relief of the site is gently rolling, erosion processes can affect soil properties [44, 45], and therefore alter the results of sample analysis. We do not recommend to combined soil samples from which the different edaphic variables are measured [11], this method can give erroneous conclusions because information at the microscale level is lost.

The geology and the topography are factors that influence the formation of particular soil type and the establishment of specific biological forms, [38]. The geological origin of rocks can be identified visually and mineralogical composition by X-ray diffraction or other methods [31]. Undisturbed rock samples must be collected, without showing any chemical or physical weathering. The slope and rock outcrops are some landscape features easy to distinguish. The slope is important by the sediments mobilized by slope processes as for landslides, colluviation, and accumulation of the material that eroded from upper landscape positions [39], this can be recorder in degrees or percent. The geomorphic position can register as summit, shoulder, back slope, toe slope, and floodplain if any (Figure 2).

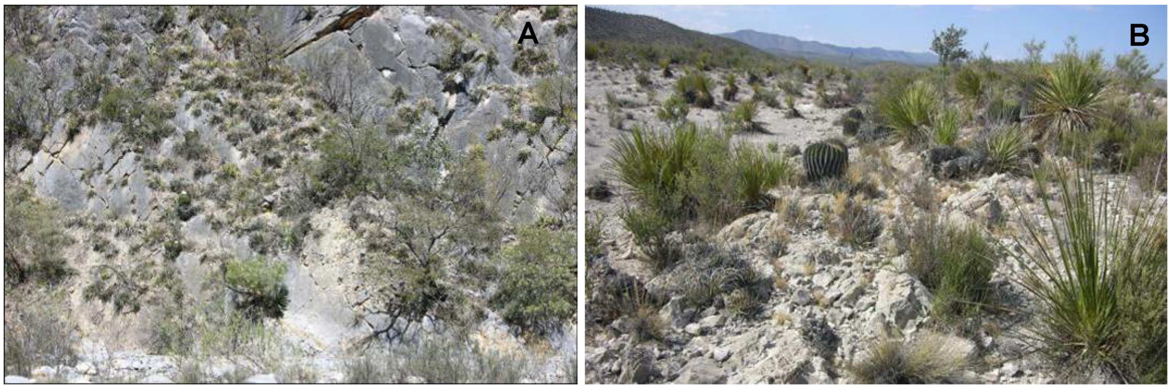

Figure 1. Delimiting study area in slope or plane environments. (A, B) Nuevo León, México. Habitats for several succulent species endemic to the Chihuahuan Desert.

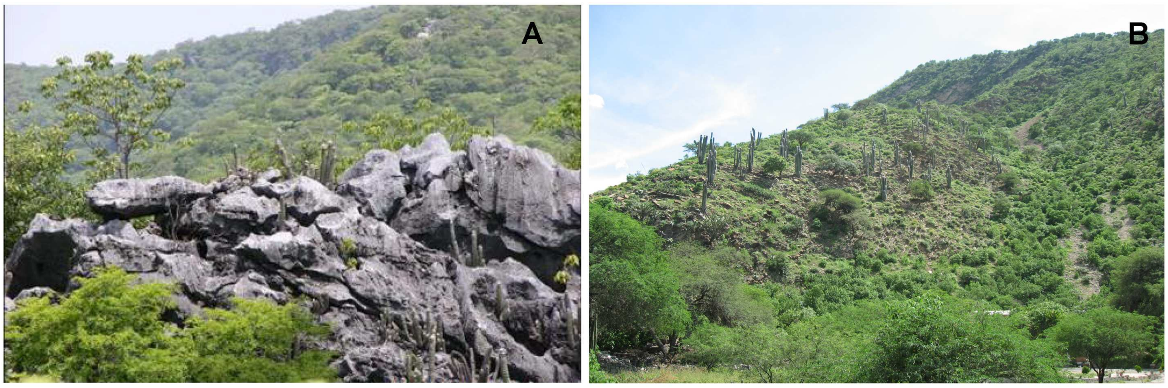

Figure 2. Geomorphic position of *Cephalocereus* species. (A) *C. nizandensis* on summit; (B) *C. senilis* on summit and shoulder.

The slope aspect would influence insolation, temperature and moisture. Isolation, temperature and moisture also must be into accounted because they have effect on the bedrock or with the vegetation [29, 77]. In the surface it is necessary to test soil and bedrock reactions to HCl as a measure of their calcareousness. Moreover, the soil properties of depth, stoniness, root distribution, H_2O_2 reaction, structure, and Munsell color should be recorded [31,54]. If the characteristics of the site permit, three or more bulk soil or rhizosphere soil and rock samples along the geomorphic position per site should be collected (Figure 3). In the cases where there was no soil, organic debris must be collected [54].

Finally, the abundance of certain minerals in the soil can influence the physiological response and metabolism in plant species, such as heavy metals accumulation and the synthesis and accumulation of biominerals [40, 53]. The most common biominerals in plant tissues are calcium oxalates (Figure 4), and their abundance is associated with calcareous soils [78]. We recommend isolate crystals from the plant tissue for better analyses and carried out X-ray diffraction (XDR), chemical composition and morphology with scanning electron microscopy (SEM). We also suggest use the petrographic microscope to know the optical properties of the crystals for be able to identify in the sand fraction of soil [57]. Additionally to relate the soil elements that plants take up soil and incorporate in their tissues, use energy dispersive X-ray (EDX) on crystals analyses. In order to determine the importance of the biominerals in the soil properties, is necessary that at least three hundred grains from the sandy fraction will count on a grain mount by line counting method using a petrographic microscope [54, 57].

Figure 3. Samples. (A) rock and organic debris for *Cephalocereus apicicephalium*; (B) soil for *C. totolapensis*.

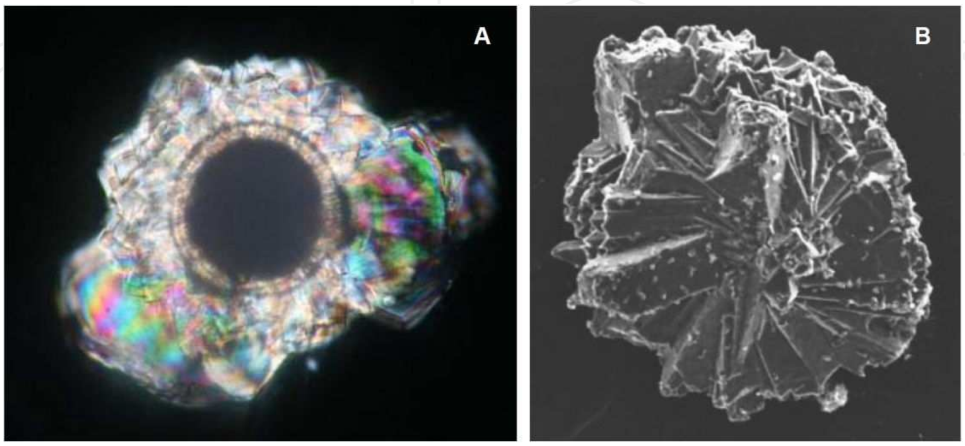

Figure 4. Calcium oxalate crystals isolated from *Cephalocereus* species. (A) petrographic microscope; (B) scanning electron microscopy.

5. Edaphic endemism

The interest for environmental conservation has been growing over the last decades. However, there has been little or no consensus on priority species or conservation strategies Table 2. The conservation of soil diversity greatly overlaps with such for plants, and both become endangered as a result of land use [46]. The fact that soil taxa are geographically restricted is important for planning and conservation efforts. Soil characteristics often play an essential role in determining plant community distributions [47]. The endemism of native plant species in edaphically specialized habitats suggest that these native endemic species are uniquely specialized to survive and grow better under the conditions prevalent in these harsh areas. For instance, several authors [48] reported there are almost five edaphically-restricted or -endemic butterflies, mostly associated with serpentine soils. Some species are absolutely limited by the edaphic restriction of their host plants. These are a better argument for biodiversity preservation [49].

Species	Evidence	Reference
Calochotus (3 spp.)	Soil studies	40
Cephalocereus (5 spp)	Soil-rock studies	54, 57
Calulanthus amplexicaulis var *barbarae*	Soil studies	59
Mammillaria fraileana	Soil-rock studies	31

Table 2. Studies in which species endemism are related to soil features.

Some explanations for the close relationship soil-plant have been looking at morpho-anatomical changes and physiological response to variations in soil parameters. Soil nutrient status determines leaves with glands or without glands: sclerophyllous (leaves without glands) plants exist almost exclusively on oligotrophic soil; whereas orthophyllous (leaves with glands) growth on more or less equally on both oligotrophic and eutrophic soil [50]. In this sense, exceptionally high levels of species turnover were found along all three soil fertility gradients which reflect the high degree of edaphic specialization of the flora [51]. Soil fertility is difficult to quantify, because it dependent not only of the nitrogen (N) and phosphorus (P) status of the soils, but also on their availability. Differences between species in ability to solubilize mineral nutrients could affect the ability or inability of plants to grow in particular soils. In calcareous soils, species suffer lime-chlorosis by Fe deficiency, and their growth is affected by inability to solubilize the native phosphate [52]. In ultramaphic soils, the vegetation accumulates large quantities of heavy metals in their tissues. So, endemic plants have developed strategies to grow successfully in these unusual conditions. For example, to minimize water requirements and excessive water loss, serpentine plants are able to reduce water potentials to levels lower than found on nonserpentine soils, as well as keep stomata closed or nearly closed [53].

Soil constitutes the main source of nutrients for plants. However, for plants growing on bare rock mycorriza have been described as an important factor in promoting edaphic specialization [35, 37]. This high degree of host specificity of symbiotic microbes could enhance nutrient uptake in the infertile soils or rocks. In rhizoplane of cacti, several bacterial species were isolated. This bacterium fixed N_2, dissolved P, weathered extrusive igneous rock, marble and limestone, and significantly mobilized useful minerals, such as P, K, Mg, Mn, Fe, Cu and Zn in rock minerals [35]. Other rock-colonizing cacti usually grow in cracks or fissures that are deeply penetrated by the root system: *Mammillaria fraileana* [31] and *Cephalocereus apicicephalium* and *Cephalocereus nizandensis* (Figure 5) [54]. Little is known about weathering mechanisms, except that the roots of these species can exude low-molecular organic acids (LOAs). The LOAs in root exudates may play an important role in the solubilization and plant availability of mineral nutrients in the rock [55]. Additionally, [20] mentioned that rock outcrop represent refuges from competition with other (often exotic) species.

Figure 5. Rocky habitats. (A) *Cephalocereus apicicephalium* grows in fissures; (B) *C. nizandensis* grows in cracks.

The edaphic endemics are now restricted to unusual and sometimes contaminated soils, but may have been able to withstand large concentrations of metals in their tissues or large quantities of calcium oxalate crystals [40]. The ability to tolerate excessively high levels of nickel and other heavy metals may be a physiological adaptation of the genus *Calochortus* and not necessarily an evolutionary response by several species to life on an ultramafic substrate. The amount of crystalline Ca oxalate in the oldest leaves of *Eucalyptus diversicolor* may be related in part to the high levels of exchange-able soil calcium [56]. *Cephalocereus* species could accumulate great quantities of calcium oxalate crystals even if there is low calcium soluble in the soil [54]. *Cephalocereus nizandensis* and *C. apicicephalium* grow on limestone outcrops, where the Ca is precipitated and *C. totolapensis* preferred acid soils from andesites, siltstones or mica schist (soluble Ca is 19-72 parts per million). The amount of soluble Ca is also very low in where grow *C. columna-trajani* (63-229 parts per million) and *C. senilis* (82-100 parts per million) [57]. The last two species have the larger epidermal crystals of the genus (Figure 6) [58].

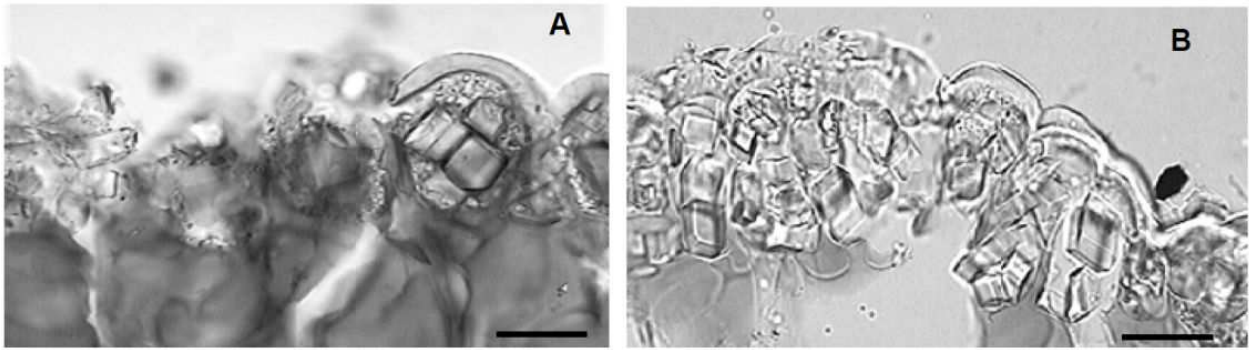

Figure 6. Prismatic calcium oxalate crystals in epidermal cells. (A) *Cephalocereus columna-trajani*; (B) *C. senilis*. Scale A = 40 μm, B = 50 μm.

For studies of evolution of a soil-type adapted endemic species is necessary to perform phylogenetic analysis. The existence of genetically compatible taxa with such distinct edaphic requirements presents a unique opportunity for intensive study of the genetic basis of tolerance to soil-type. A group plant may have evolved in a very dynamic selective context with strong edaphic selective pressures. In [59] they examined phylogenetic relationships of the rare serpentine endemic taxon *Caulanthus amplexicaulus* var. *barbarae*. They found that the serpentine taxa were nonmonophyletic evolving independently at least three times, suggesting that tolerance to serpentine may be gained or lost through relatively few genetic changes. In other case, [50] construct phylogeny for the *Pentaschistis* clade with 82 species in three genera. They investigated the association between leaf anatomy type and soil nutrient type on which species grow. Despite there is little phylogenetic constrain in soil nutrient type. However, only orthophyllous-leaved species diversify on eutrophic soils. Nevertheless, modern phylogenies on a number of phanerogam genera occurring on New Caledonia (*Acianthus*, *Cupaniopsis*, *Guioa*, *Morinda*, and *Oxera*) have shown a shift in soil preference (from non serpentine to serpentine soils and vice versa). Thus [60] concluded that the ability to grown on serpentine soil is either a plesiomorphic or a very homoplasious character and therefore the hypothesis that serpentine soils preserve the indigenous flora in New Caledonia against competition with immigrant species cannot be supported for these groups. Rarely are made specific soil studies, the data are taken often of general charts. We suggest making detailed studies as in *Cephalocereus*, according to plant species and soil type [57]. Therefore, it might be possible to infer the role of soil in the evolution of endemic plant species using the phylogenetic analysis.

6. Conservation strategies

In the landscape, the vegetational differences often serve to delineate the geologic discontinuities of an area even to the casual observer. The remarkable differences often observed in plant cover for different soil types in adjacent areas, have naturally led to attempts to explain these phenomena in terms of the physical or chemical properties of the soil, or of the physiological characteristics of the plants [61]. These areas should be priority sites for conservation to preserve the unique interaction between soil and plant species as well as the microbiota and fauna. For example, the halophytic and gypsophytic vegetation of the Ebro-Basin at Los Monegros [62] or flora of the Coastal Calcareous Hills of the Biosphere Reserve Baconao in Cuba [63] are excellent to demonstrate the varied adaptations of plant types and life-forms as strategies to survive on edapho-climatic harsh conditions of various kinds. In the Chihuahuan Desert region it was found that several Cactaceae species, particularly many members of the Cacteae tribe often inhabit extremely specialized habitats, such as gypsum and other unusual soil formations (Figure 7) [64]. The patches of edaphic endemism also frequently exist as refuges for native species in highly invaded ecosystems [20], ultramafic substrates act as sites in which *Pinus balfouriana* escapes of the competition [65]. Moreover, the work with *Helianthus exilis* showed the need to protect specialized microhabitat found only within the large serpentine outcrops, the species cannot survived outside the narrow conditions proper of its habitat [66]. However, the scarcity of conclusive studies on role of soil to determine the prevalence of endemic plants hampers the efforts of public and private organizations to preserve such areas.

Figure 7. A) *Aztekium ritterii* grows in outcrops of steep slopes of crystalline grypsum; (B) *Turbinicarpus valdezianus* grows in calcarious rocks.

The population size can greatly vary among populations of the same specie generating micro-endemic nature. The small populations of some species consist of adult individuals that may be 3 as in *Cephalocereus totolapensis* [54] or 4 as in *Guaiacum unijugum* [67]. These population sizes are not reported sometimes considerer no significant, but many regions show a unique assemblage of species or a higher level of species richness or other associated species which could serve to protect this ecosystem. In Australian alpine vegetation the analyses of the relationships between physiognomic variation and environment indicate that edaphic factors are more important than climatic factors in differentiating formations [18]. Thus, edaphic discontinuities should be determining the size and population distribution and should be considered when proposing conservation areas.

Frequently, endemic species are less widely distributed and are less well represented in protected areas than other threatened species [68]. Baconao Biosphere Reserve presents high floristic composition and which endemic species represent 21%; however they are restricted at limestone hills, parent material that cover only 6.6% of total area [63]; and the same applies when registering Asteraceae endemic species to the Mexican state of Oaxaca with 53.4% and many of them not found in any Biosphere Reserve [69]; in the same sense, 12 endemic plant species are restricted to serpentine soil in Puerto Rico, all rare, uncommon and very localized within their limited distribution, and only two have been placed on the United States Federal list as threatened or endangered [70], and most species endemic to the state of Nuevo Leon (Northeast of Mexico) present in the submontane scrub have restricted distribution and specially cacti are not located within any protected area [71]. Therefore it is important to reconsider the extension of the sites identified as irreplaceable for various members of the flora endemic worldwide.

The effects of growing human populations on natural communities, on ecosystems, and on some endemic plant populations results in degraded state of sites due to human activity as roadway, tourist development, extraction of mineral as gravel, sand, and others. However, an understanding of the interrelations between soil or bedrock and occurrence of endemics, becomes even more important in the context of restoration ecology and the reversal of land degradation. In addition, the role of soil in the determination of endemic plants has not been sufficiently studied; thus, public and private organizations have not intensified their efforts to preserve such areas. Table 1 show some examples of the different soils supporting endemic species and how through different techniques of study has been able to establish a close relationship between soil and plant. As can be seen, the soil-plant endemism is not exclusive to one type of soil or a plant family.

7. Conclusions

Diverse studies have demonstrated that soil characteristics are correlated with differences in bedrock. Although incipient and timid studies intend to respond to which extent do soil characteristics correlate with vegetation patterns, this is a question that should not be forgotten in plant endemic studies.

We cannot do random sampling hoping to find a relationship between habitat and population size or presence / absence of some species. Efforts should be directed to characterize the habitat or habitats where the species grows in order to determine whether the type of soil, rock, and bedrock are the most important factors for endemic species development. When the limiting factor is the substrate, and abrupt limit in abundance is expected, as well as in population parameters. Narrow endemism in plants is frequently related to soil specificity, and many endemic plants are found in patches of certain soil within a different soil matrix. Additionally as with the soil, vegetation usually changed abruptly at the contact zone.

Edaphic endemic plants are highly vulnerable to extinction due to stochastic events, habitat degradation, climatic change, and invasion by weedy species. Finally, the protected areas may be unable to maintain regional species diversity and representativeness, especially if additional fragments are lost and fragmented landscapes are left unmanaged and they are fragile to soil erosion or degradation by chemical contamination.

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